PATENT SPECIFICATION

DRAWINGS ATTACHED

898,160

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International Classification:—**G08c, F06d, h. G01d, l.**

COMPLETE SPECIFICATION

Fluid Pressure Responsive Apparatus and Servo Apparatus therefor

We, THE GARRETT CORPORATION, a Corporation organised under the laws of the State of California, United States of America, of 9851—9951, Sepulveda Boulevard, Los Angeles 45, California, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to fluid pressure responsive apparatus and more particularly to regulated fluid pressure transducer systems for producing output quantities which are a function of fluid pressures coupled to the system.

Often fluid pressures are sensed by a pressure transducer to provide useful outputs. In aircraft, air data computing systems include atmospheric pressure altimeter systems which provide both electrical and mechanical outputs for control of the flight of the aircraft, e.g. control of the flight by an autopilot. These output quantities, which are functions of true static or atmospheric pressure, are necessarily precise in order to maintain preset altitudes and to control the rate of ascent or descent.

Typical output quantities of altimeter systems are static pressure, log of static pressure or altitude, incremental of log of static pressure and rate of change of log of static pressure. These outputs are required to be extremely accurate due to the speed of the aircraft in which they are being employed. Further, the response of the system must be very rapid without oscillation or hunting, for the slightest error, slow response, or oscillation will produce an erratic flight pattern of the aircraft and excessive oscillation of the aircraft about a preset altitude.

Other specific requirements of the altitude control systems include the elimination of non-linearities of components in the system and errors resulting therefrom and maintaining substantially a predetermined signal level in the system for improved and uniform response over the entire range of operation.

According to one aspect of the invention fluid pressure responsive apparatus includes a balanced beam subject to differential forces from a first bellows and a second bellows, including an auxiliary lever formed in two parts, a pair of knife edges both connected to the movable end of the second bellows, the first acting on the main beam and the second acting on one part of the auxiliary lever, and a third knife edge connected to the movable end of the first bellows and acting on the other part of the auxiliary lever in opposition to the second knife edge of the second bellows, the two parts of the auxiliary lever being relatively adjustable so as to vary the ratio of the couple exerted on it by the third knife edge to the couple exerted on it by the second knife edge. The first bellows is preferably evacuated. The two parts of the lever are conveniently relatively adjustable through a position in which the second and third knife edges are directly opposite so that the leverage ratio is unity.

The second or third knife edge may be formed in two collinear parts spaced apart and carried respectively by the limbs of a forked member, whilst the other of those knife edges is situated between them, the part of the lever co-operating with the latter knife edge being sandwiched between two limbs of the other part of the lever co-operating respectively with the two parts of the former knife edge.

The invention may be carried into practice in a number of ways but one specific embodiment will now be described by way of example with reference to the accompanying drawings in which:—

Figure 1 is a block diagram of an embodiment of the invention;

Figure 2 is an isometric exploded view of the mechanism;

Figure 3 is an enlarged sectional view of a detail of the adjustable compensating cam;

Figure 4 is a detailed sectional view of a portion of the transducer; and

Figure 5 is a section along the line 5—5 of Figure 4 looking in the direction of the arrows.

This embodiment incorporates the features of the present applicant's British Patent Specification Nos. 29123/61 and 29124/61 (Serial Nos. 898,161 and 898,162) which are divided out of the present specification.

Figure 1 shows a fluid pressure transducer closed loop regulated system including a pressure transducer 10 for sensing ambient fluid or atmospheric pressure and producing an output force proportional to it and a feedback element 12 coupled to a system output which is required to be proportional to the said pressure for producing a balancing force output. The output forces of the pressure transducer and feedback element are mechanically applied to a comparison element 14 for comparing them and hence comparing the input pressure with the actual output of the system (which is required to be proportional to the input pressure).

The comparison element 14 includes means for producing an electrical error signal which is proportional to the difference between the transducer input and the feedback force.

In many instances, the level of the error signal obtained from the comparison element is insufficient to drive output elements 16. In the preferred arrangement, therefore, the transducer system includes amplifier circuits 17 for amplifying the error signal from the comparison element to provide an amplified signal capable of driving the output elements 16.

Often, as in pressure type altimeter equipment, the output elements are driven exponentially, or at an increasing rate, with decreasing fluid pressures. In atmospheric or static pressure altimeter systems, for example, the altitude increases exponentially with decreasing static pressure. The foregoing exponential non-linearity may be provided for in the system either electrically or mechanically, for example as shown in the drawings by cam gears.

Decreasing pressure increments with altitude introduce a change in signal level which can be compensated for by a variable gain control 18 that is preferably driven by a mechanical element in accordance with static pressures. The variable gain control serves to vary the gain of the amplifier circuits for maintaining the signal level and the power in the system at a more uniform signal level.

Figure 2 shows diagrammatically the details of one embodiment of a regulated fluid pressure transducer system according to the present invention. The pressure transducer generally indicated at 10 comprises an evacuated bellows 23 having one end fixed to a base 36 and a static pressure bellows 22 the interior of which communicates through a tube 22^1 with the static openings of a pitot-static tube, not shown. The evacuated bellows 23 compensates for variations of the pressure bellows output which are not the result of static pressures, including the response to fluid pressures in the chamber surrounding the bellows 22 and other variations excluding atmospheric pressures coupled to the bellows 22 by the tube 22^1.

A resultant force depending on the forces exerted by the bellows 22 and 23 is applied, through a coupling device described in detail later with reference to Figures 4 and 5, to a main lever or balance beam 20 mounted on a fulcrum 21.

The force exerted by the bellows 22 and 23 is applied near one end (the left in Figure 2) of the beam 20 and is balanced by a force applied near the other end from one end of a precision torsion spring 24, of which the other end is deflected in accordance with the output intended to correspond with the force exerted by the bellows. Hence if the beam is balanced the output is correct but if there is a lack of balance the beam is deflected and this indicates that there is an error and that appropriate adjustment of the output is required.

The deflection of the beam is detected by a differential transformer 30 having a movable core carried between the spaced member of a forked extension 25 of the beam. The direction and amount of displacement of the transformer core determines the amplitude and phase of an output signal which is supplied to a preamplifier 31 by leads 33. Movement of the beam is damped by a damping unit 39. Temperature variations affecting the comparison element are substantially eliminated by bimetallic or other temperature compensating elements coupled to the movable core of the differential transformer 30.

The output of the preamplifier 31 is fed to a power amplifier 53 by leads 32 where the signal level is raised to drive a servo motor-tachometer 40. The direction and speed of the motor are determined by the phase and amplitude of the amplified signal from the differential transformer 30. In addition the motor tachometer gives an electrical output, which, as will be understood later is proportional to the rate of change in log of atmospheric pressure. This electrical rate of pressure change signal may be fed to an automatic pilot or other equipment, as desired, by leads 34^1, and is also fed back to the preamplifier by leads 34 to provide a negative feedback for stabilising the preamplifier.

A gear train 41 couples the rotational output of the motor-tachometer 40 to a pair of electromagnetic clutches 43 and 44. One of the

clutches, depending upon the speed of the system, is engaged to drive a subsequent gear train 45 to provide a mechanical output proportional to log of atmospheric pressure or altitude at a shaft 54 and an output proportional to atmospheric pressure at a shaft 55. The output shafts 54 and 55 are connected through a cam logarithmic gear coupling, including cam gears 46 and 47, which is designed so that if the angular rotation of the shaft 55 is proportional to change in static or atmospheric pressure, then the rotation of the shaft 54 will be proportional to change in log of atmospheric pressure or altitude.

As described in more detail below, the shaft 55 is connected to one end of the precision torsion spring 24 so that the compensating force applied to the beam 20 to balance the force due to the bellows 22 and 23 is proportional to the displacement of the shaft 55. This ensures that the motor 40 goes on moving the shaft 55 until its displacement truly represents atmospheric pressure, and hence the displacement of the shaft 54, due to the cam gears, represents the logarithm of atmospheric pressure, and hence altitude.

In addition to the mechanical outputs, an electrical output proportional to variations from a reference altitude is provided by a synchronous transmitter 52 coupled to the gear train 45 through a clutch 50 and provided with a return to null mechanism 51. The electromagnetic clutches are connected to a control power supply 49 through switches 48. The clutches 43 and 50 are engaged when energised while the clutch 44 is disengaged when energised. The alternative paths provided through the electromagnetic clutches 43 and 44 provide for regulation of speed through the gear train 45.

It will be apparent from the foregoing that a number of both mechanical and electrical system outputs which are functions of the atmospheric pressures or altitudes are vailable; the first being the electrical signal representing rate of change in log of atmospheric pressure which may be taken from lines 34[1] coupled to the motor-tachometer 40, the second being the electrical signal from the transmitter 52 representing the incremental change in log atmospheric pressure or incremental change in altitude from the altitude selected by energization of the clutch 50, the third being the rotation of shaft 54 representing change in log of atmospheric pressure, and the fourth being the rotation of shaft 55 representing change in atmospheric pressure.

Referring now to the feedback portion of the system one end of the torsion spring 24 is securely clamped to a disc 81 which is held in position on a hub 82 coupled to a cam 83 by a suitable friction sleeve 85. The sleeve 85 provides a friction coupling between the hub 82 and the cam 83, whereby the torque of the spring 24 may be adjusted. This arrangement is particularly suitable for adjustments preliminary to or at the time of installation in an aircraft.

The preload from the spring 24 tends to turn the cam gear 47 in the direction of the arrow "A". As illustrated the cam gears 46 and 47 are positioned for the maximum altitude within the range of the system. In order to maintain approximately the same gear tooth load with varying spring torque over the operating range of the system, a backlash arrangement is provided including a coil spring 98 acting on an arm 99 pivoted to the base at a point 100 and a roller 101 riding on a periphery of the cam 83. As the atmospheric pressure is increased, such as at lower altitudes, the extended lobe of the cam 83 acting against the force of the spring 98 decreases the torque transmitted from the torsion spring 24 to the cam gear 47 for uniform loading of the cam gears.

The torque of the torsion spring 24 is transmitted to the balance beam 20 through a variable lever feedback compensating arrangement by which non-linearity in the torque of the spring and other undesired non-linearities in the system may be reduced or substantially eliminated. This compensating arrangement includes a retainer 70 which is adapted to be clamped to one end of the coil spring 24 by suitable clamping means 71 positioning the end of the coil around the shaft 74 and a bearing 75 for locking it in position. The retainer member 70 has a radial arm 77 carrying a rod affording a knife edge 78 for transmitting a force corresponding to the spring torque to a lever 104 and thence to the balance beam 20.

The knife edge 78 engages the lever 104 at a V-slot 103. The far end of the arm 104 (the right in Figure 2) is coupled to the beam 20 by a tube 105 clamped in an opening in the lever 104 by a screw 106. The tube 105 retains one end of a flexure wire 107 of which the other end is retained by a tube 108 passing through and secured to the balance beam 20.

To compensate for undesirable non-linearities in the system, over the entire range of its operation, the lever 104 is provided with a movable fulcrum 122 for varying the force applied to the balance beam from the knife edge 78. The fulcrum 122 is movable under an undercut portion 112 of the lever 104, and its position is controlled by an annular cam 115 coaxially secured to the end portion of the shaft 74. On the inner periphery of the cam, a thin flexible band forming the cam surface 119 is retained by an inwardly extending circular flange 118.

Around the outer periphery of the cylindrical portion of the cam, and preferably located centrally between its edges, are a plurality of threaded openings extending to receive

adjusting screws 121 for warping the thin flexible band 119. The lobes or irregularities in the cam surface provide for adjustments to compensate for non-linearities including non-linearity of the torsion spring.

The fulcrum 122 is biased by a tension spring 126 against the arm of a cam follower 123 to move the fulcrum in accordance with the cam surface. Both the cam follower and the movable fulcrum are pivoted to a base at 124 and are initially adjusted relatively to one another by an adjusting screw 125 threaded through a lug or the like in the arm of the cam follower 123, whereby adjustments of the set screw position the arm of the movable fulcrum relative to the cam follower. Preferably, the movable fulcrum 122 includes a roller 127 rotatably secured to the end of the arm and adapted to ride on the lower surface of the lever 104.

Similarly, a pair of rollers 128 and 130, shown in the enlarged detail sectional view in Figure 3, are carried on the end of the cam follower arm 123 coaxially and laterally adjacent one another so that the roller 130 provides a reference position when riding on the circular flange 118. In the absence of lobes or linearity adjustments of the flexible cam surface 119, the cam follower remains stationary as the roller 130 rides on the circular flange. Cam lobes formed by the flexible cam surface 119 engage the roller 128 to move the cam follower and the movable fulcrum for varying the ratio of the lever and eliminating undesired non-linearities in the balancing force applied to the beam 20.

Also mounted on the shaft 74 is a drum 117 carrying actuating strips 137 and 138 for a pair of limit switches 143 and 144. The actuating strips project sufficiently from the cylindrical surface of the drum 117 to operate the respective limit switches which are coupled to the pre-amplifier for reversing the phase of the signal coupled to the motor-tachometer 40 which is a two-phase motor so that phase reversal reverses the direction of rotation. This feature has been provided to limit the rotation of the shaft 74 to less than 360°, the exact limits of the angular rotation being determined by the positioning of the actuating strips 137 and 138. In one embodiment of the system, the angular rotation is limited to 270° by separating the bevelled edges of the strips 137 and 138 by 90° as viewed in Figure 2. The limiting arrangement permits the system to adjust to a new range of pressures or altitudes without a delay in response. If desired, a single limit switch may be used to provide the foregoing function by peripheral alignment of the strips 137 and 138 with the limit switch's actuating member.

For controlling or adjusting the loop gain of the servo system, a rod 129, projecting longitudinally from the cylindrical cam 115 is received in a slotted arm 131 which is mounted for rotation on a shaft 132 of a gain control potentiometer 133, mounted coaxially with the shaft 74. Since the system, as shown, is at the higher end of its pressure or altitude range, the potentiometer 133 is providing for maximum gain of the amplifier 53 to maintain the signal level and power in the system substantially constant and compensate for the decrease in variation of pressure for a given change in altitude at higher altitudes.

Figures 4 and 5 show the coupling device for coupling the bellows 22 and 23 to the balance beam 20. The pressure bellows 22, which is subjected to static pressure is rigidly secured to a knife edge 61, engaging the main balance lever or beam 20, and also to a knife edge 63 engaging a V-notch in a yoke portion 60 of a two-part auxiliary lever. The latter also includes a slide portion 26 having a V-notch to receive a knife edge 27 rigidly secured to the evacuated bellows 23. As shown in Figure 5 the knife edge 63 is formed in two collinear halves spaced apart on opposite sides of the knife edge 27 to which they are directly opposed.

The yoke 60 is connected to the base 36 by a spring blade 65 providing a fulcrum.

The slide portion 26 of the two-part lever is adjustably secured in the yoke portion 60 for controlling the ratio of the lever and thereby compensating for tolerance differences in areas of the pressure and evacuated bellows. A clamping screw 29 releasably secures the adjustable member 26 to the yoke 60. It is seen therefore, that the knife edges 63 and the knife edge 27 are not necessarily directly in alignment and equidistant from their common fulcrum formed by the flexible member 65 unless the bellows areas are equal, the knife edge 27 being adjustable relatively to the knife edges 61 and 63 to compensate for any mismatching of the pressure and evacuated bellows.

In operation the transducer system shifts as the pressure bellows 22 detects an atmospheric pressure change for example in the tube 22^1 from the pitot static line of an aircraft. The change in atmospheric pressure, which it is assumed results from a change in altitude in the present embodiment, unbalances the beam 20. The unbalancing of the beam displaces the core of the differential transformer to produce a linear AC output of one of two phases.

The amplitude output signal of the differential transformer 30 is proportional to the displacement of the transformer core. This signal amplified in the pre-amplifier 31, and the power amplifier 53, drives the motor-tachometer 40.

The motor-tachometer has an electrical output signal proportional to the rate of change in altitude or log of pressure. This output signal is coupled back to the pre-amplifier as a regenerative feedback signal. The gear trains

are driven by the motor-tachometer to provide a mechanical output in which the position of the shaft 54 indicates log of atmospheric pressure or altitude, and the position of shaft 55 indicates atmospheric pressure. The cam gears 46 and 47 coupling the shafts 54 and 55 convert altitude or log of atmospheric pressure movements to atmospheric pressure movements while within the gear transmission, the electromagnetic clutches 43 and 44 and associated spur gears provide for a speed changing function in which two speed modes have been provided. The low speed mode is used under normal operating conditions, while the high speed transmission is required for fast-tracking rates, for example, aircraft slewing conditions.

The feedback element includes the precision torsion spring 24 which is coupled to the pressure output shaft 55 through an adjustable sleeve 85, for initially adjusting the torque of the torsion spring, and an anti-backlash arrangement including the cam 83 and cam follower 99.

The feedback or torsion spring output is communicated to the beam to provide a balancing force which is proportional to the change in atmospheric pressure as indicated by the actual output of the system on the shaft 55. The torque from the torsion spring 24 is transmitted to the beam 20 by a variable coupling arrangement for modifying the force applied to the beam through the feedback path over the range of operation of the system. This arrangement includes a lever having a movable fulcrum for transmitting the torque from the spring to the beam. The movable fulcrum 122 varies the lever ratio, and is controlled by the cam 119 and cam follower 128 which has been adjusted to correct for the undesired non-linearities in the system including the non-linearities of the torsion spring 24.

In addition to the rate of change in altitude output derived from the tachometer, which is also a function of the rate of climb and descent in pressure altimeters, a second electrical output is provided which is a pressure or altitude signal derived from the synchronous transmitter 52. The clutch 50 engaging the synchronous transmitter may be energised automatically or manually at any given altitude within the range of the system. The synchronous transmitter output signal will be proportional to the incremental change in altitude from the said given reference altitude. The incremental altitude signal may be used to control an aircraft by the autopilot to maintain the aircraft's altitude within very close limits of the predetermined reference altitude. The signal is also useful in air data computers.

In the preferred arrangement, the rotational shaft outputs which are proportional to altitude and pressure, cover the full range of altitude and pressure in approximately 180° rotation. The altitude output shaft has high torque transmission characteristics and may be used to drive a variety of mechanical or electrical readout devices. In addition to being coupled to the feedback elements, the output shafts may also be directly connected to an air data computer to drive various pressure function devices. The rotation of the pressure shaft output is proportional to atmospheric pressure and may be utilised in the same manner as the altitude output shaft, with respect to atmospheric pressure functions instead of altitude functions.

While the system has been described in connection with a certain preferred embodiment of the invention as specifically disclosed, it is understood that the invention is not limited to precision altimeters or even to supply outputs for air data computers but is applicable to many variations of fluid pressure transducer systems.

WHAT WE CLAIM IS:—

1. Fluid pressure responsive apparatus including a balanced beam subject to differential forces from a first bellows and a second bellows, including an auxiliary lever formed in two parts, a pair of knife edges both connected to the movable end of the second bellows, the first acting on the main beam and the second acting on one part of the auxiliary lever, and a third knife edge connected to the movable end of the first bellows and acting on the other part of the auxiliary lever in opposition to the second knife edge of the second bellows, the two parts of the auxiliary lever being relatively adjustable to as to vary the ratio of the couple exerted on it by the third knife edge to the couple exerted on it by the second knife edge.

2. Fluid pressure responsive apparatus as claimed in Claim 1 in which the first bellows is evacuated.

3. Apparatus as claimed in Claim 1 or Claim 2 in which the two parts of the lever are relatively adjustable through a position in which the second and third knife edges are directly opposite so that the leverage ratio is unity.

4. Apparatus as claimed in any one of the preceding claims in which the second or third knife edge is formed in two collinear parts spaced apart and carried respectively by the limbs of a forked member, whilst the other of those knife edges is situated between them, the part of the lever co-operating with the latter knife edge being sandwiched between two limbs of the other part of the lever co-operating respectively with the two parts of the former knife edge.

5. Apparatus as claimed in any one of the preceding claims in which the auxiliary lever has a fulcrum formed by a flexible strip.

6. Fluid pressure responsive apparatus as specifically described herein with reference to Figure 4 of the accompanying drawings.

7. Servo apparatus as specifically described herein with reference to the accompanying drawings.

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Chartered Patent Agents,
Agents for the Applicants.

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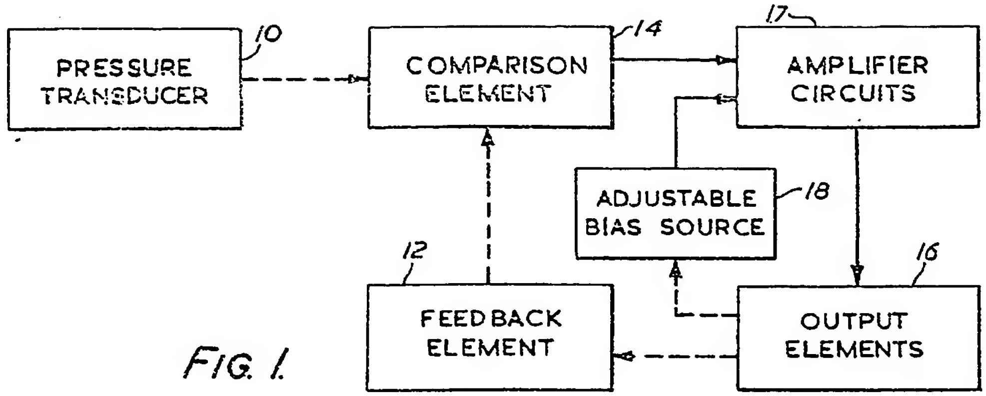
PRESSURE TRANSDUCER
10
COMPARISON ELEMENT
14
AMPLIFIER CIRCUITS
17
ADJUSTABLE BIAS SOURCE
18
FEEDBACK ELEMENT
12
OUTPUT ELEMENTS
16

FIG. 1.

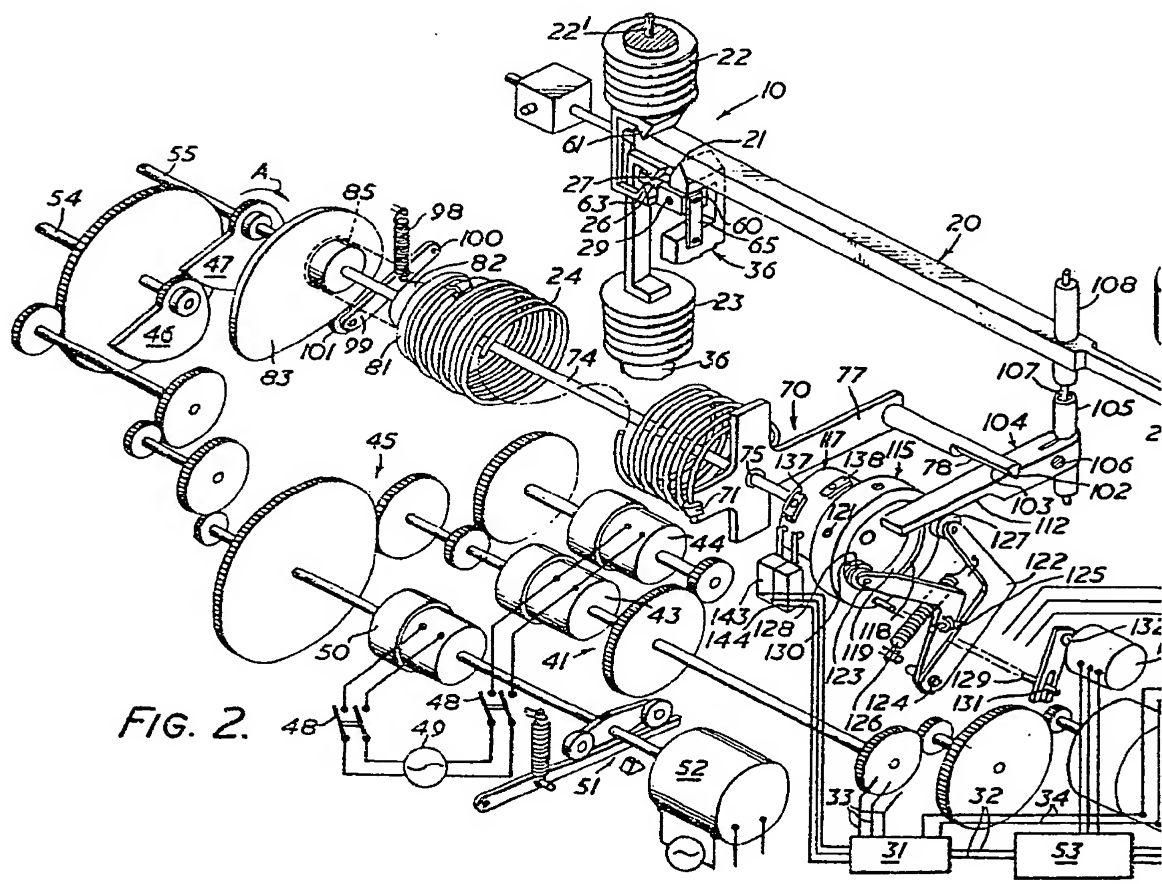

FIG. 2.

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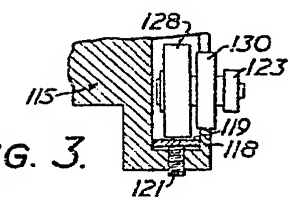


FIG. 3.

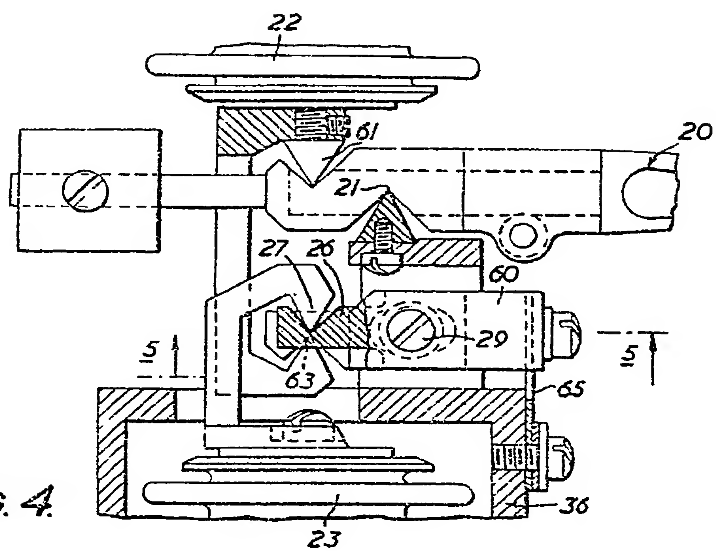
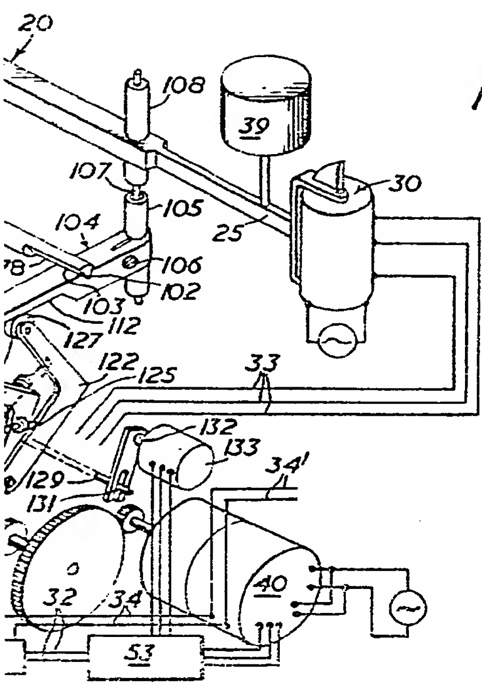


FIG. 4.



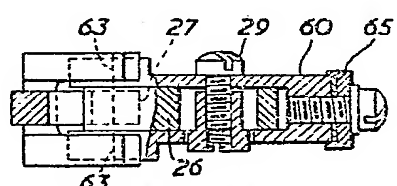


FIG. 5.

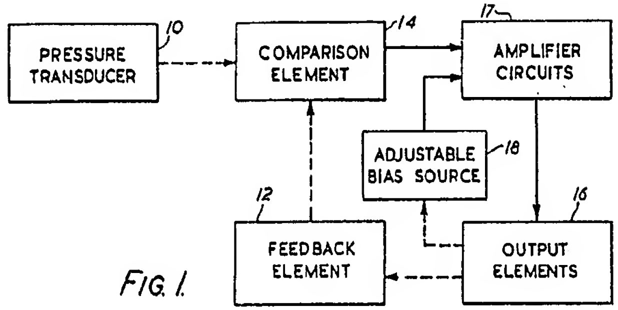


FIG. 1.

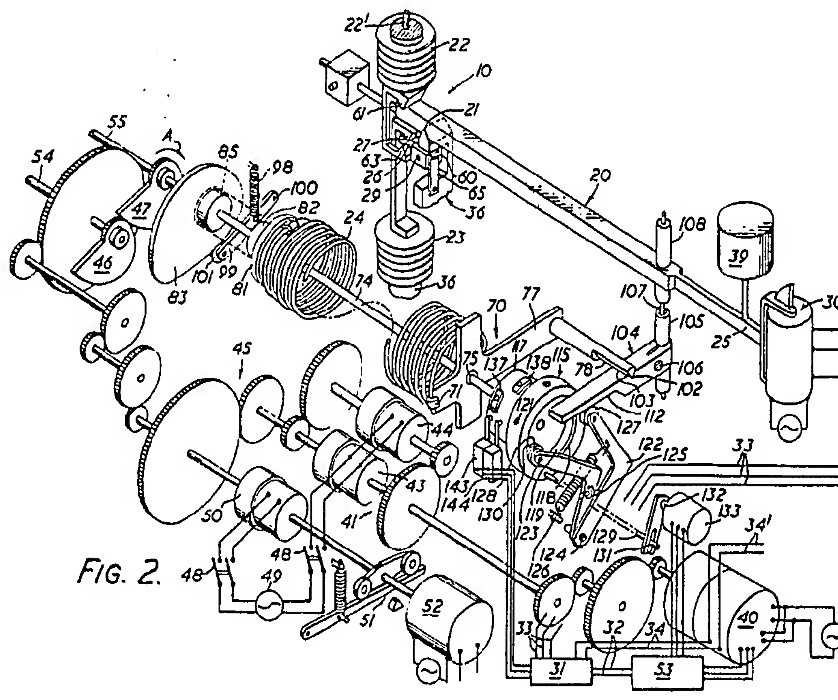


FIG. 2.

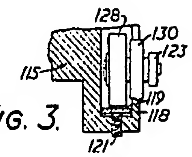


FIG. 3.

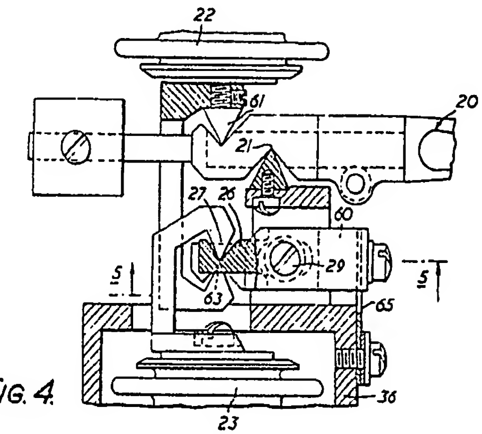


FIG. 4.

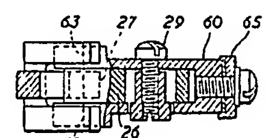


FIG. 5.

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